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A COMPARISON OF THE UNIT OF LUMINOUS INTENSITY OF THE UNITED STATES WITH THOSE OF GERMANY, ENGLAND, AND FRANCE.

By Edward P. Hyde.

In inaugurating the work in photometry at the Bureau of Standards several years ago it was decided to adopt at once a working standard which could be maintained uniform, and in terms of which lamps submitted for verification could be standardized, and to defer the adoption of a primary standard until a thorough investigation of various primary photometric standards could be made. A comparison of the standards used by a large number of incandescent lamp manufacturers in the United States showed differences of 10 per cent or more and emphasized the need of authoritative photometric standards, copies of which could be supplied to lamp manufacturers and others making photometric measurements.

Obviously it was desirable to have the secondary standard which was to be maintained at the Bureau in as close agreement as possible with the standards employed in industrial practice in the United States. In the gas industry the British parliamentary candle is the recognized primary standard and has been used quite generally as the working standard, although in recent years it has been supplanted to some extent by the Harcourt (10-cp) pentane lamp. In the photometry of electric lamps, following the recommendation of the American Institute of Electrical Engineers, the Hefner lamp has been recognized as the primary standard, but the luminous intensity of a source has been expressed in British parliamentary candles, using the ratio 1 Hefner = 0.88 British candle.

The British candle is thus universally the unit of luminous intensity in the United States, and it was therefore adopted as the unit in terms of which the standard of the Bureau should be expressed.

But the British candle as a standard is unreliable and may have values differing by 5 per cent or more, so that the value of a candle unit obtained from a standard sperm candle would not be satisfactory. It was therefore decided to obtain the candle unit in the way recommended by the American Institute of Electrical Engineers, with one essential difference. Since Hefner lamps which do not differ in intensity from the standards of the Reichsanstalt by more than 2 per cent, are certified by that institution as correct, and since, owing to the difference in color between the Hefner lamp and ordinary illuminants, comparisons between the Hefner and other sources depend somewhat on the observer, two observers using different certified Hefner lamps may obtain results differing by several per cent. Therefore, instead of measuring at the Bureau a number of incandescent lamps in terms of several Hefner lamps in our possession, the Hefner unit was obtained directly from the Reichsanstalt by means of incandescent lamps verified at that laboratory in terms of their Hefner lamps. In this way it was hoped to obtain a standard expressed in terms of the Hefner unit of the Reichsanstalt.

The unit of the Bureau was obtained from these lamps by the use of the ratio, 1 Hefner=0.88 candle. This unit was found to be in approximate agreement with the mean value of the candle in use by many lamp factories and testing laboratories, and was therefore in no sense an innovation. Since the establishment of the unit, all the principal lamp factories and testing laboratories have obtained copies of it directly or indirectly, so that this unit has now become in practice as well as in theory the standard of the United States in the photometry of electric lamps.

Since obtaining the original lamps, several comparisons of the standard of the Bureau with that of the Reichsanstalt have been made by means of seasoned incandescent lamps sent to Germany, each comparison indicating that the ratio of our unit to that of the Reichsanstalt had remained unchanged to within the errors of observation. Moreover, measurements made both at the Reichsanstalt and at the Bureau of Standards on incandescent lamps belonging to the Electrical Testing Laboratories of New York[1] showed the Bureau unit to equal very closely $\frac{100}{88}$ of the Reichsanstalt unit.

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[1] Sharp: Trans. International Electrical Congress, St. Louis, **I**, p. 492; 1904.

In order to obtain an accurate comparison of the unit of the United States with those of England and France, and to obtain a further comparison with the unit of Germany, the writer carried a number of seasoned lamps abroad in the spring of 1906, and had them compared with the recognized standards of these countries. Eighteen lamps were taken, nine of which were 50-volt, 64-watt, horseshoe filament lamps which had been standardized for intensity in a specific direction defined by lines etched on the bulb. The other nine lamps were 110-volt, 64-watt, oval anchored filament lamps which had been standardized for mean horizontal intensity (the mean intensity perpendicular to the axis of the lamp) by the method of rotating the lamps at 180 revolutions per minute. Three lamps of each type were left at the National Physical Laboratory at London as a check on the others which were taken to Paris and Berlin.

The lamps were hermetically sealed in copper boxes and were carried entirely by hand in order to avoid excessive jarring. They were taken in the order named to the National Physical Laboratory, the Laboratoire Central d'Électricité at Paris, the Physikalisch-Technische Reichsanstalt at Berlin, and then again to the National Physical Laboratory. They were intercompared and measured in terms of the standards of the Bureau immediately before leaving and as soon after returning as practicable.

At each laboratory, except the Reichsanstalt, the method employed for determining the mean horizontal intensity of the six 110-volt lamps was the same as that used at the Bureau. At the Reichsanstalt the method of rotating a pair of mirrors about the lamp was employed. Moreover, the distance at which both the stationary and rotating lamps were measured was approximately 125 cm at each laboratory except the Reichsanstalt, where the 50-volt stationary lamps were compared at a distance of 300 cm, and the other six lamps at a distance of 450 cm. The difference in distance was occasioned by the use of the *two* mirrors in measuring the mean horizontal intensity of the 110-volt lamps.

An investigation was subsequently undertaken at the Bureau to determine what differences in the values of mean horizontal intensity might result from the two different methods of making the measurements. The results of this investigation, which was extended to a study of all the possible errors incident to the determination of mean horizontal intensity by the rotating-lamp method, are given in a separate paper in the last volume[2] of this Bulletin. For oval anchored filament lamps the values of mean horizontal intensity determined in the two ways would probably not differ appreciably, although it is impossible to conclude definitely from the results obtained by one observer what the results would be for a second observer. The flicker, which is plainly perceptible even with lamps of the oval anchored filament type rotating at 180 revolutions per minute, is more annoying and more productive of error with some observers than with others. Two observers at the Bureau, however, obtained correct values of mean horizontal intensity for these lamps to within negligible differences.

The possible errors due to the difference in distance at which the measurements were made were also investigated, by comparing the intensities of the lamps at a long distance with their intensities at a much shorter distance, using the rotating sectored disk. In the case of the stationary lamps a bad centering of the filament produces different apparent intensities at different distances. With the rotating lamps images are cast by the bulb in different directions and at various distances from the lamp, and the light radiating from these images has of course a different effective center from that radiating directly from the filament. In the orientation of stationary lamps care is always exercised to avoid a direction in which an image is thrown, but in rotating a lamp the light in every direction in the horizontal plane falls on the screen so that it must be shown by experiment what differences in the apparent intensities obtained at different distances may result from these images. Although the error due to such an effect would no doubt be quite appreciable if measurements were made with the lamp in such a stationary position that an image would fall directly on the screen, in rotating the lamp the effect of such images is distributed over the entire horizontal zone, so that the resultant error would probably be small. A comparison of the lamps at 300 cm and at 125 cm revealed no appreciable differences, so that the measurements made at the Reichsanstalt are comparable with those made in England and France and at this Bureau.

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[2] Vol. 2, p. 415.

The results of the determinations made in England were obtained by comparison with incandescent lamps, which in turn had been compared with the standard Harcourt pentane lamp of the National Physical Laboratory. This lamp is supposed to have an intensity of 10 British parliamentary candles, and therefore the intensities of the incandescent lamps verified for the Bureau are expressed in British candles. In France the comparisons were made against incandescent lamps which had been measured at the Laboratoire Central in terms of the Carcel lamp. By assigning to the Carcel lamp an intensity of 9.6 bougies décimales, a value obtained by Violle from a direct comparison with the platinum standard, the results are expressed in bougies décimales.

In Germany the comparisons were made against incandescent lamps which had in turn been compared against the Hefner amyl acetate lamp. The results are expressed in Hefner candles. Since at the Reichsanstalt the electromotive force of a Clark cell at 15° C is taken as 1.4328 volts, instead of 1.4340 volts (the value used in England, France, and the United States), the voltages and currents of the incandescent lamps were modified accordingly, but in the following tables, for purposes of comparison, all voltages and currents are expressed in terms of the same units.

In Table I are given the complete results obtained for the individual lamps at the different laboratories, in the order in which the laboratories were visited. The first six lamps, B. S. Nos. 44, 45, 46, 49, 50, and 64, are the 50-volt stationary lamps, the remaining six, B. S. Nos. 4, 7, 8, 13, 30, and 40, are the 110-volt lamps that were standardized for mean horizontal intensity and are hereafter designated as the *rotating* lamps. The six lamps, three stationary and three rotating, which were left at the National Physical Laboratory, are not included in this table. They were used merely as a check on the constancy of the other twelve lamps.

In the first column are given the numbers of the lamps, in the second column the voltages at which the lamps were burned, and in the remaining columns the values of candlepower and current found at the respective laboratories. At the Bureau of Standards and at the National Physical Laboratory they were measured twice. The values given in the fifth and sixth columns are those obtained at the first visit to the National Physical Laboratory, but since for

TABLE I.

Values of Candlepower and Current Obtained at the Different Laboratories.

Lamps	Voltage	Bureau of Standards		National Physical Laboratory		Laboratoire Central		Reichsanstalt		National Physical Laboratory		Bureau of Standards	
		Candle-power	Current	Candle-power	Current	Candle-power in bougies décimales	Current	Candle-power in Hefner's	Current	Candle-power	Current	Candle-power	Current
B. S. No. 44...	49.0	17.4_1	1.3326	17.6_8	1.3330	17.7_0	1.3325	19.9	1.333	17.7_2	1.3330	17.3_8	1.3325
B. S. No. 45....	49.0	17.3_1	1.3304	17.6_3	1.3306	17.5_5	1.330	19.6	1.331	17.4_2	1.3306	17.2_4	1.3302
B. S. No. 46 ..	49.5	17.3_1	1.3225	17.6_3	1.3229	17.5_7	1.323	19.5	1.323	17.6_0	1.3230	17.2_8	1.3225
B. S. No. 49...	49.5	17.5_9	1.3301	17.7_9	1.3302	17.7_5	1.3295	19.9	1.330	17.7_4	1.3305	17.5_2	1.3301
B. S. No. 50....	49.5	17.3_8	1.3283	17.5_8	1.3284	17.5_0	1.328	19.6	1.328	17.5_0	1.3288	17.3_0	1.3282
B. S. No. 64....	50.5	17.7_0	1.3328	17.9_5	1.3325	18.0_0	1.333	20.1	1.333	18.0_0	1.3331	17.6_8	1.3328
Means	....	17.4_5	1.3294	17.7_1	1.3296	17.6_8	1.3293	19.7_7	1.3297	17.6_6	1.3298	17.4_0	1.3294
B. S. No. 4....	109.0	16.2_5	0.5973	16.5_0	0.5975	16.5_5	0.5965	18.5	0.597	16.5_1	0.5975	16.1_5	0.5974
B. S. No. 7....	108.0	15.9_0	0.5947	16.1_1	0.5944	16.0_5	0.5937	18.0	0.594	16.2_5	0.5946	15.8_8	0.5944
B. S. No. 8....	109.0	16.0_2	0.5851	16.3_0	0.5852	16.4_0	0.5850	18.3	0.584	16.3_0	0.5852	16.0_5	0.5850
B. S. No. 13....	109.0	15.7_8	0.5936	16.0_7	0.5938	16.4_0	0.5932	18.1	0.593	16.0_8	0.5939	15.8_1	0.5937
B. S. No. 30....	109.0	15.7_8	0.5852	16.0_4	0.5855	16.0_5	0.5848	18.0	0.585	16.0_8	0.5855	15.7_3	0.5854
B. S. No. 40....	109.0	16.2_5	0.5984	16.7_3	0.5986	16.7_0	0.5970	18.6	0.598	16.6_4	0.5986	16.3_1	0.5984
Means	....	16.0_0	0.5924	16.2_9	0.5925	16.3_6	0.5917	18.2_5	0.5923*	16.3_1	0.5926	15.9_9	0.5924

* The current values in this column were only given to three decimal places by the Reichsanstalt, but since the corrections for difference in value of the standard cell amounts to 5 in the next place for the rotating lamps, and is the same for all the lamps, the mean is increased by 5 in the fourth decimal place.

lack of time only a single set of readings was made, the results are not guaranteed by the National Physical Laboratory to a high accuracy. They are therefore omitted in the final comparisons of the units.

Table I reveals several interesting and important facts in regard to the present stage of development of the science of photometry. A comparison of the mean values of the stationary and rotating lamps before being carried abroad and after their return gives some idea of the constancy and portability of seasoned incandescent lamps as secondary photometric standards. The lamps were carried about for two months, were packed and unpacked five times, were burned in all about two or three hours, and yet the mean value of the six stationary lamps was found to have changed by less than 3 parts in 1000, while the mean value of the six rotating lamps apparently changed less than 1 part in 1000. It is not to be inferred from this that the lamps necessarily remained as constant as the results would indicate, since it is impossible to measure with certainty even the mean value of the lamps with an accuracy better than several parts in 1000. The constancy of the resistance of the lamp filaments as shown by the agreement between the mean current values is another indication of the constancy of the lamps and emphasizes the importance of accurate electrical measurements in the photometry of incandescent lamp standards.

A second interesting fact, on which some light is thrown by Table I, is the ultimate accuracy of photometric comparisons. Of course this accuracy depends largely on the nature of the sources to be compared, their color, relative intensity, constancy, etc. Moreover, any single observer with a particular set of apparatus may at any one time, or even at different times, obtain relative values between the two different sources to a remarkably high degree of accuracy. A very important question, however, is the accuracy with which different experienced observers using different apparatus can obtain the relative values of two light sources under favorable circumstances.

This question is partially answered by Table I. The conditions of comparison—at least for the stationary lamps—were as nearly ideal as could be realized with any known sources. The lamps were all of the same color (the voltages having been chosen initially to accomplish this); they were approximately of the same intensity, and those of each type burned at approximately the same voltage. The observers were experienced in photometry, and the measurements were made in laboratories of international reputation, but the apparatus and the methods of measurement employed were somewhat different.

In order to show the agreement among the different measurements the results are expressed in a more convenient way in Table II. Since the units of the different countries are not the same the values of the individual lamps are expressed in terms of the mean of the six lamps taken as unity.

TABLE II.

Relative Values of Individual Lamps in Terms of Mean.

Lamps	Bureau of Standards	National Physical Laboratory	Laboratoire Central	Reichsanstalt	National Physical Laboratory	Bureau of Standards	Mean Relative Values
B. S. No. 44	0.998	0.998	1.001	1.007	1.003	0.999	1.001
B. S. No. 45	0.992	0.995	0.993	0.991	0.986	0.991	0.991
B. S. No. 46	0.992	0.995	0.994	0.986	0.997	0.993	0.993
B. S. No. 49	1.008	1.005	1.004	1.007	1.005	1.007	1.006
B. S. No. 50. ...	0.996	0.993	0.990	0.991	0.991	0.994	0.992
B. S. No. 64	1.014	1.014	1.018	1.017	1.019	1.016	1.016
Means	1.000	1.000	1.000	1.000	1.000	1.000	1.000
B. S. No. 4	1.016	1.013	1.012	1.014	1.012	1.010	1.013
B. S. No. 7	0.994	0.989	0.981	0.986	0.996	0.993	0.990
B. S. No. 8	1.001	1.001	1.002	1.003	0.999	1.004	1.002
B. S. No. 13	0.986	0.986	1.002	0.992	0.986	0.989	0.990
B. S. No. 30	0.986	0.995	0.981	0.986	0.986	0.984	0.985
B. S. No. 40	1.016	1.027	1.021	1.019	1.020	1.020	1.020
Means	1.000	1.000	1.000	1.000	1.000	1.000	1.000

In the first column are given the numbers of the lamps, the first six being the stationary lamps and the last six the rotating lamps. The next six columns contain the relative values of the lamps as determined at the various laboratories indicated at the head of the respective columns. The last column contains the mean relative values of the individual lamps, being the means of the values in the preceding six columns. If these mean relative values are taken as the true values of the lamps, by comparing them with the values in the other columns, an idea is obtained of the accuracy with which the individual lamps were measured in terms of the six standards. It is seen that the greatest deviation from the true value is only 0.7 per cent for the stationary lamps and 1.2 per cent for the rotating lamps, whereas the average deviation for the measurements at any one laboratory is in no case as large as 0.3 per cent for the stationary lamps, or 0.5 per cent for the rotating lamps. The accuracy of reading is naturally somewhat less with the rotating lamps than with the stationary lamps, as the flicker for oval anchored filaments rotating at 180 revolutions per minute is quite perceptible and annoying, even to observers accustomed to it.

In comparing the relative values found at the different laboratories with the mean relative values it should be noted that the Reichsanstalt only certified the lamps to one-tenth of a Hefner candle, and therefore the relative values calculated from the Hefner candle values given by that laboratory are only significant to within several units in the last decimal place in Table II. Moreover, as stated above, the first values given by the National Physical Laboratory represent only a single set of readings, and consequently the agreement between the two columns of values given by that institution should not be compared with the agreement between the two columns of values found at this Bureau, and which represent the mean of a number of determinations.

In order to compare the unit of the Bureau with those of the other laboratories, the values given in Table I are grouped in a more convenient form in Table III. In this table the unit of each laboratory is expressed in terms of the unit of the Bureau of Standards, except that the Reichsanstalt unit is expressed in terms of 0.88 times the Bureau unit. The ratios are given as obtained both from the stationary and from the rotating lamps, and it is interesting to note the differences between the two values. In every case the ratio obtained from the rotating lamps is lower than that obtained from the stationary lamps. This difference, which amounts to 0.7 per cent at one of the laboratories, may be due in part to causes discussed in the paper referred to above on the errors incident to the rotating lamp method of measuring mean horizontal intensity. It may also be due in part to small errors in electrical measurements. Although all of the stationary lamps were of one type and all of the rotating lamps were of one type, these two types were not the same. The stationary lamps were 50-volt lamps, taking a current of 1.3 amperes, whereas the rotating lamps were 110-volt lamps, with currents of 0.6 amperes, so that the electrical conditions in the two cases were quite different.

TABLE III.

Values of Units of Different Laboratories in Terms of the Unit of the Bureau of Standards.

Units of Various Laboratories	Values in Terms of B. S. Unit		
	Stationary Lamps	Rotating Lamps	Means
Bureau of Standards unit	1.000	1.000	1.000
Reichsanstalt unit	1.001×0.88	0.996×0.88	0.998×0.88
National Physical Laboratory unit	0.987	0.981	0.984
Laboratoire Central unit	0.985	0.978	0.982

It is seen from Table III that the unit of the Bureau is equal to $\frac{100}{88}$ of the Reichsanstalt unit to within the errors of measurement. Since the unit was originally obtained in this way nearly four years ago it indicates that the Bureau has maintained through incandescent lamp secondary standards, a unit which, compared with the unit of the Reichsanstalt, has not changed appreciably in that time. But though the Bureau has been able to maintain for several years a constant unit by means of incandescent lamp secondary standards, and could probably continue to maintain it in this way for an indefinite period, nevertheless the need of a suitable primary photometric standard is fully recognized and an investigation of primary standards will be undertaken in the near future.

It is evident from Table III that the value of the British candle obtained from the Hefner by the use of the fraction 0.88, which is supposed to represent the mean of the best determinations of the ratio, is not the same as the British candle defined in terms of the Harcourt (10-cp) pentane lamp at the National Physical Laboratory. The difference is about 1.5 per cent, according to the values given in Table III; but, as will be seen later, there is an uncertainty in this ratio amounting to several per cent. Before passing to a brief résumé of the recent determinations of the ratios of the three lamps recognized as standards in England, France, and Germany, it is desirable to call attention to the approximate agreement between the bougie décimale, the British candle, and the candle in use in the United States in the testing of electric lamps. The difference of about 2 per cent is small compared with the accuracy usually obtained in industrial photometry, and no serious results would follow a compromise by which the three countries would agree upon a unit to be the same for all. This highly desirable end will become more difficult of accomplishment each year, as a higher accuracy of photometric measurement is demanded, and even now a change in unit of over 1 per cent would be felt in the United States. Unfortunately the unit of Germany is so different from all the others that it would probably be impossible to agree upon a unit common to the four countries, but the ratio of the Hefner candle to the candle of France, England, and the United States could be accurately fixed.

The question of a uniform unit is to be distinguished from that of a uniform standard lamp in terms of which the unit is expressed. Thus at present the Carcel lamp in France has an intensity of 9.6 bougies décimales, and the Harcourt pentane lamp in England has an intensity of 10 British candles. Only in Germany has the standard an intensity of one unit, and even here in stating the intensity the word *candle* is affixed (Hefnerkerze). Of course it would be very desirable to adopt a common standard as well as a common unit, but the adoption of the unit is the more important of the two. As soon as an entirely satisfactory standard is presented, its general adoption will probably follow, and this is much more likely to result if the adoption of a new standard does not entail the adoption of a new unit. The Hefner lamp was recommended by the Geneva Congress as a secondary standard, but owing partly to the fact that the Hefner was not found as satisfactory in other laboratories as it had been found at the Reichsanstalt, and partly, no doubt, because of the different value of the unit, its general adoption did not follow. The Carcel continues to be used in France, and the Harcourt pentane lamp is coming into general favor in England.

In 1903 the commission which was appointed by the Paris International Congress of Gas Engineers to fix rules for the photometry of gas burners decided, upon hearing the report of Doctor Bunte, that the ratios of the three standards, the Hefner, the Carcel, and the Harcourt (10-cp) lamp, were not sufficiently well determined, and recommended that determinations of these ratios be made at competent laboratories in Germany, France, and England. The most probable values of these ratios, as given by Bunte,[1] are reproduced in part in Table IV.

TABLE IV.

Most Probable Ratios of the Hefner, Carcel, and Harcourt (10-cp) Lamps as Given by Bunte.

	Hefner	Harcourt (10-cp)	Carcel
Hefner	1.0	0.088	0.092
Harcourt (10-cp)	11.4	1.0	1.05
Carcel	10.87	.95	1.0

In response to requests from the commission new determinations of the ratios of the three lamps have been undertaken in laboratories of England, France, and Germany, and the results of some of these investigations have already been published. The values found at the Reichsanstalt[2] are given in Table V.

TABLE V.

P. T. R. Values of Harcourt (10-cp) and Carcel Lamps in Terms of Hefner Candles.

Intensity of Harcourt (10-cp) lamp = 10.9 HK
Intensity of Carcel lamp = 10.7 HK

The value of the Harcourt lamp is given for the atmospheric conditions adopted as standard at the National Physical Laboratory, which are a barometric height of 760 mm of mercury, and a humidity of 10 liters of water vapor in one cubic meter of pure, dry air. The value given for the Carcel lamp was 10.8 Hefner candles at a

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[3] Recueil des Travaux et Compte rendu des Séances de la Commission internationale de Photométrie. Première Session, Zurich, 1903, p. 45.

[4] Zs. für Instrumentenkunde, **26**, p. 186; 1906: also Liebenthal, Jour. für Gasbeleuchtung, **49**, p. 559; 1906.

humidity of 8.8 liters of water vapor in one cubic meter of pure, dry air; but since the atmospheric conditions adopted as normal in Paris[3] are the same as those normal to England, the value was corrected accordingly in order to make the results comparable in the various tables.

In France comparisons were undertaken both at the Laboratoire Central d'Électricité and at the Laboratoire d'Essais. The results of the comparisons at the former laboratory have been published in full[4], and in an appendix the results obtained at the Laboratoire d'Essais are summarized. At the Laboratoire Central the comparisons were made principally by measuring each lamp against incandescent lamps, but a few experiments were made in which the lamps were compared directly one against another. The results of these last experiments are combined with the results obtained at the Laboratoire d'Essais where but one method was employed, viz, that of comparing the lamps directly one against another. The values which will be submitted by the French laboratories to the International Commission are given in Tables VI and VII, in which the intensity of each lamp is reduced to the value it would have under the atmospheric conditions adopted as normal to the respective country.

In Table VI are given the results obtained at the Laboratoire Central by indirect comparison through incandescent lamps. In Table VII are given the means of two series of measurements made

TABLE VI.

Ratios Determined at Laboratoire Central by Indirect Comparison Through Incandescent Lamps.

	Carcel	Hefner	Harcourt (10-cp)
Carcel	1.0	10.76	1.0
Hefner	0.0929	1.0	0.0929
Harcourt (10-cp)	1.0	10.76	1.0

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[5] Laporte et Jouaust, Bulletin de la Société Internationale des Electriciens, Series 2, 6, p. 375; 1906.

[6] Laporte et Jouaust, loc. cit.

at the Laboratoire d'Essais and one series made at the Laboratoire Central, all by direct comparison.

TABLE VII.

Ratios Determined at Laboratoire d'Essais and Laboratoire Central by Direct Comparison.

	Carcel	Hefner	Harcourt (10-cp)
Carcel	1.0	10.73	0.991
Hefner	0.0932	1.0	0.0933
Harcourt (10-cp)	1.009	10.72	1.0

The results of the comparisons made at the National Physical Laboratory have not as yet been published in full, but in the summary of the work of the Reichsanstalt for the last year,[5] where the results of the measurements made at the Reichsanstalt are given, the values given in Table VIII are recorded as having been determined at the National Physical Laboratory. The value of the Carcel lamp is corrected to the values it would have under normal atmospheric conditions.

TABLE VIII.

N. P. L. Values of Harcourt (10-cp) and Carcel Lamps in Terms of Hefner Candles.

Intensity of Harcourt (10-cp) lamp = 10.95 HK
Intensity of Carcel lamp = 10.68 HK

In the determinations of the ratios made at the various laboratories, of necessity different lamps were employed. At each laboratory the respective lamp or lamps recognized as the standard of the laboratory were probably used, but at the Laboratoire Central, for example, the Hefner and Harcourt (10-cp) lamps that were used were not the particular lamps that are taken as the standards of the Reichsanstalt and the National Physical Laboratory, respectively, so that any lack of reproducibility of any of the standards might cause differences in the ratios determined at the different laboratories. It is interesting therefore to compare these ratios with those calculated from the values assigned by the various laboratories to the twelve incandescent lamps of the Bureau of Standards. The ratios calculated from the incandescent lamp measurements are given in Table IX. In making the computations the intensity of the Carcel lamp was taken as 9.6 bougies décimales, the Harcourt (10-cp) lamp as equal to 10 British candles, and the Hefner lamp as equal to 1 Hefner candle.

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[5] Loc. cit.

TABLE IX.

Ratios Calculated from Intensities Assigned to B. S. Incandescent Lamps.

	Harcourt (10-cp)	Hefner	Carcel
Harcourt (10-cp)	1.0	11.19	1.043
Hefner	0.0893	1.0	0.0932
Carcel	0.959	10.73	1.0

It would seem that the values obtained through the incandescent lamps are in some ways the more accurate ratios of the *units* of the various countries, because the primary standard of each country is operated under the usual conditions by the most experienced observers

TABLE X.

Summary of Ratios of Hefner, Harcourt (10-cp), and Carcel Lamps.

	Harcourt (10-cp) / Hefner	Carcel / Hefner	Harcourt (10-cp) / Carcel
Reichsanstalt (using an electric comparison lamp)	10.9	10.7	1.02
Laboratoire Central (using an electric comparison lamp)	10.76	10.76	1.00
Laboratoire Central and Laboratoire d'Essais (direct comparison)	10.72	10.73	1.009
National Physical Laboratory	10.95	10.69	1.024
Ratios computed from Bureau of Standards incandescent lamps	11.19	10.73	1.043
Best previous values (Bunte)	11.4	10.87	1.05

with the respective lamp, whereas in the direct comparisons different lamps are used, and the conditions of operation in the different countries may be slightly different from the conditions normal to the laboratory in which the respective lamp is a standard.

The ratios obtained at the various laboratories together with the values obtained through the Bureau of Standards incandescent lamps and the best previous values, as given by Bunte, are summarized in Table X. It is seen from this table that the best agreement is obtained in the ratio of the Carcel lamp to the Hefner lamp, whereas discrepancies amounting to 4 or 5 per cent occur in the other ratios. The most important result to engineers of the United States is the discrepancy in the ratio of the Hefner candle to the British candle as given by the Harcourt (10-cp) lamp. The value given by Bunte as the best previous ratio is 0.88, and so is the same as that recommended by the American Institute of Electrical Engineers and adopted by the Bureau. This value, however, is 2 per cent different from that obtained through the Bureau of Standards incandescent lamps, and 5 or 6 per cent different from the values found at the various laboratories. If, therefore, the British candle be taken as one-tenth the intensity of the Harcourt (10-cp) pentane lamp at the National Physical Laboratory, according to the values assigned the Bureau of Standards incandescent lamps, it is 2 per cent different from the candle in this country obtained from the Hefner lamp by using the ratio 0.88. If the British candle be taken as one-tenth the intensity of any Harcourt (10-cp) lamp, it would seem from Table X to be different from the candle in this country by 5 or 6 per cent. Whatever the amount of the difference, it would seem that the candle in use in the photometry of electric lamps in the United States is sufficiently different from the British candle, as obtained through Harcourt (10-cp) pentane lamps, to justify defining the unit obtained through the Hefner by use of the ratio 0.88 as the *candle* instead of the *British candle*. It is hoped, however, that the suggestion made in a previous paragraph in regard to an international *unit* may be carried out, and that by a constant intercomparison of the standards of the different countries by the interchange of electric incandescent lamps the unit may be maintained uniform.

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